COMPACT POLARIMETRY POTENTIALS

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ABSTRACT

The goal of this study is to show the potential of a compact-pol SAR system for vegetation applications. Compact-pol concept has been suggested to minimize the system design while maximize the information and is declined as the π/4, π/2 and hybrid modes. In this paper, the applications such as biomass and vegetation height estimates are first presented, then, the equivalence between compact-pol data simulated from full-pol data and compact-pol data processed from raw data as such is shown. Finally, a calibration procedure using external targets is proposed.

Index Terms— Compact polarimetry, biomass, vegetation height, PolInSAR, raw data, calibration.

1. INTRODUCTION

The compact polarimetry (CP) mode has already been presented in three forms: π/4 [1], π/2 [2-3] and the hybrid mode [3-4], the latter being a particular case of the π/2 mode. Previously, some applications using compact polarimetric data have been shown [4-5], e.g. a classification of the scattering types with the conformity coefficient, the Faraday rotation estimate modulo π and the soil moisture estimate. In this paper, two other applications in CP are presented. The potential for quantifying the biomass and for retrieving the vegetation height with compact-pol data simulated from RAMSES P-band data is proposed. These two previous applications are done with CP data simulated from FP processed and calibrated data. In the third part of this paper the equivalence between compact-pol data simulated from full-pol data and compact-pol data processed from raw data as such is shown. The calibration requirements and procedure are investigated in the last part of this paper.

2. BIOMASS ESTIMATE

Beaudoin et al. showed [6] that the cross-polarized returns has the highest sensitivity of backscattering coefficients to trunk biomass, considering a full-polarized SAR system. With a SAR system operating in a CP mode, the cross-polarized channel (i.e. HV) is missing. The challenge is then to examine whether the reconstructed cross-pol (HV') channel [1-2] from CP data following the approach suggested by Souyris has also a good relationship with biomass or whether CP data are directly related to forest biomass. The measured biomass is shown to correlate with the backscattering coefficients at HV, HV' and RR polarizations using data acquired over the Nezer forest at P-band, cf. Fig.1.

Using the regression deduced from the relationship between measured biomass and backscattering coefficients, the biomass is then estimated. The comparison between estimated and measured biomass is displayed in Fig.2 at the top of the next page. The comparison between the estimated and measured biomass for the three channels HV, HV' and RR shows a very good agreement. The RMS error for HV is 5.8 tons/ha over a maximum forest biomass of 120 tons/ha. This is the reference result. The RMS error for the compact-pol channels is in the same order of magnitude as the full-pol channel since for HV' it is only 0.4 tons/ha higher than for HV and 0.8 tons/ha higher for RR. The coefficients of the quadratic regression $\left(B_{xy} = a\sigma_{xy}^2 + b\sigma_{xy} + c\right)$ and the RMS errors are listed in the Table 1:

Polarization	a	b	c	r²	RMS error(tons/ha)
HV	0.5368	18.476	188.2	0.96	5.8
HV'	0.8579	22.489	178.15	0.95	6.2
RR	0.9752	9.0446	51.907	0.94	6.6

Table 1: Quadratic regression coefficients and RMS errors of biomass estimates over RAMSES P-band CP data. Note that the biomass range is [25;120] tons/ha.

3. VEGETATION HEIGHT ESTIMATE

Now, the interferometry concept is added to analyse the abilities of a compact polarimetric system to estimate the volume height at low frequencies. The Random Volume over Ground (RVoG) [7-8] model allows to obtain volume height estimate from full-PolInSAR (F-PolInSAR) data. Dubois-Fernandez et al. [2] presented the direct application of RVoG model to compact PolInSAR (C-PolInSAR) data.

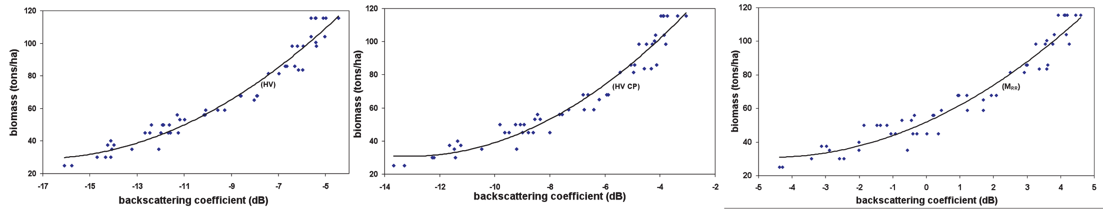


Fig. 1: biomass as function of backscattering coefficients at HV, HV' and RR channels over Nezer forest at P-band.

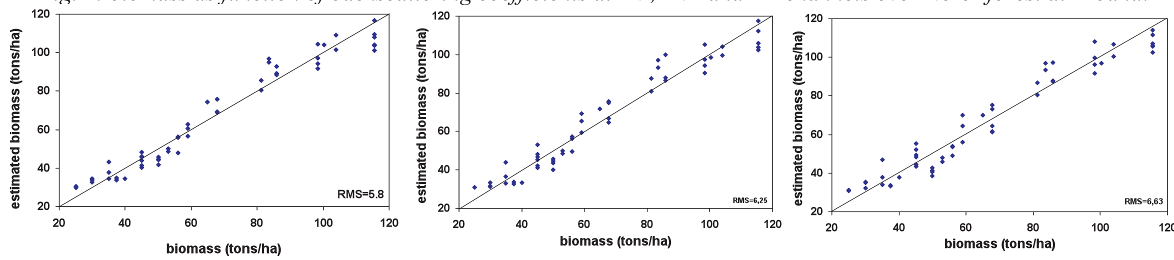


Fig.2: comparison between estimated and measured biomass at HV, HV' and RR channels.

They showed that it is possible to estimate the forest height but in some cases, the canopy height estimate can be degraded compared to the results obtained by using F-PolInSAR data. In this paper, we show an alternative approach to estimate the line that best fits the coherence region using Flynn et al. algorithm [9]. The compact interferometric scattering vector using a single circular transmission and two independent receptions is a two-element vector which allows the representation of the compact-PolInSAR information by a 4x4 matrix. Note that the C-PolInSAR coherence region is included in the F-PolInSAR coherence region as shown in Fig.3.

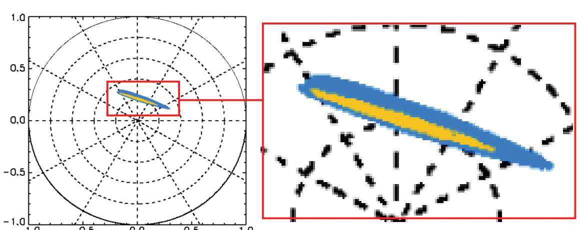
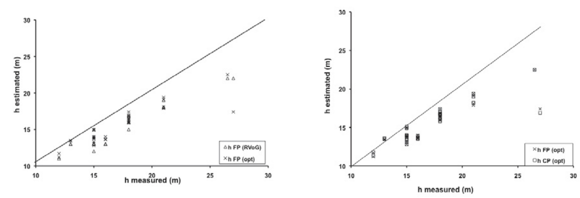


Fig.3: Representation of the inclusion of the C-PolInSAR coherence region (in yellow) in the F-PolInSAR one (in blue).

Standard RVoG inversion is based on 3 to 5 interferometric coherences (γ_{HH}, γ_{VV}, γ_{HV}, γ_{HH+VV}, γ_{HH-VV}). These coherences are not accessible from C-PolInSAR measurements and an alternative is proposed which considers the full extend of the coherence region, therefore minimizing the loss of information. The approach was first proposed by Flynn et al. [9] for FP data and is adapted to CP here, identified as *opt* method. So using Flynn et al. algorithm [9] we plot the boundary of the coherence region. The two lines resulting from the C-PolInSAR dataset and the F-PolInSAR dataset are then compared. The inversion is performed assuming a fixed attenuation (required hypothesis as the volume only coherence is not observed), cf Fig.4.



(a) (b)

Fig.4: (a) Height estimates with F-PolInSAR data using RVoG and the method presented vs measured height, (b) height estimates with F-PolInSAR and CPolInSAR data using this method vs measured height.

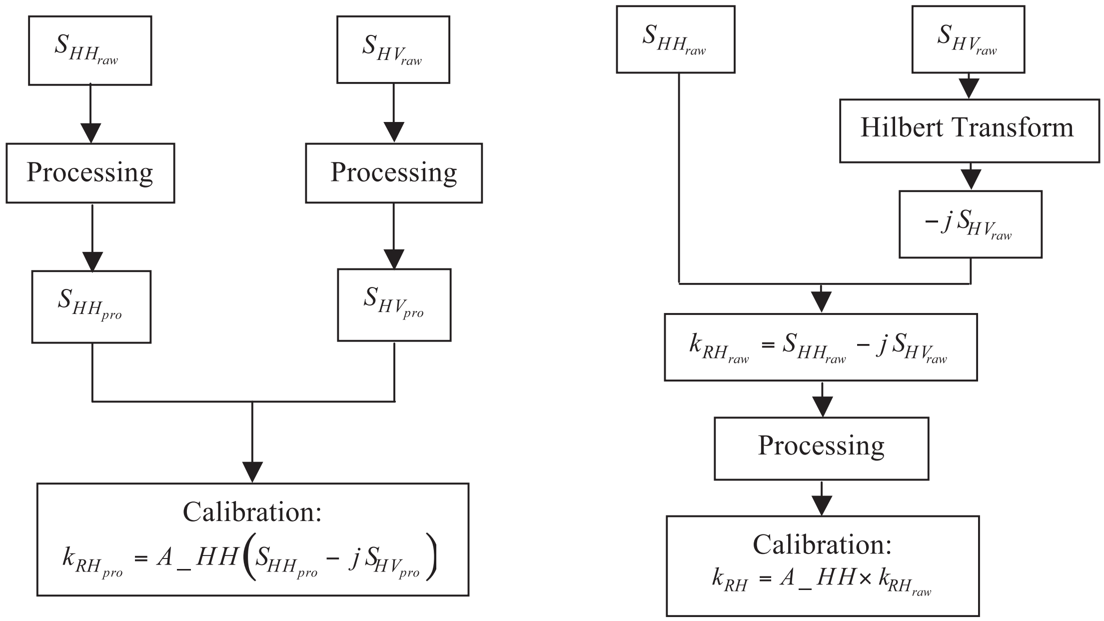
4. RAW DATA

If a system operates in a CP $\pi/2$ mode, the backscattering vector $\vec{k}_{\pi/2}$ is made up of two elements $\vec{k}_{RH}$ and $\vec{k}_{RV}$. The element $\vec{k}_{RH}$ simulated from FP raw data is called $\vec{k}_{RH\_raw}$ and is the compact-pol raw data whereas the one simulated from FP processed and calibrated data is called $\vec{k}_{RH\_pro}$:

$$\vec{k}_{RH\_raw} = S_{HH_{raw}} - j\,S_{HV_{raw}}$$

$$\vec{k}_{RH\_pro} = S_{HH_{pro}} - j\,S_{HV_{pro}}$$

With S_{HHraw} and S_{HVraw} the output raw FP signals from demultiplexer, whereas S_{HHpro} and S_{HVpro} are FP signals already processed. The two processes of construction of the CP are explained by the following diagrams (cf. Fig.5 at the top of the next page). The same processes can be done with $\vec{k}_{RV}$. Finally using these two backscattering vectors $\vec{k}_{\pi/2_{raw}}$ and $\vec{k}_{\pi/2_{pro}}$, a complete comparison is performed, on the amplitude as well as on the phase. The overall interferometric coherence between the two images is very close to one and always higher than 0.9.



(a) *(b)*

Fig.5: Diagrams showing the two processes. (a) construction of the CP from FP data already processed. (b) construction of the CP from FP raw data.

5. CALIBRATION

In a full-polarimetric context, ignoring the system gain function and noise, the calibration is done based on external targets like a trihedral and distributed targets enforcing the reciprocity principle. Once the distortions, i.e. channel imbalance and cross-talk, are estimated, it is possible to correct the system (i.e. to retrieve the Sinclair matrix elements) by computing an inversion matrix. In the π/2 context with a circular transmission, it has been shown that it is not possible to correct the transmission afterwards as only one polarization is transmitted [11] and it is illustrated in the diagram at the bottom of this page. So considering now that the system is almost perfect in transmission, 5 distortion parameters need to be corrected. We suggest a procedure to calibrate such a system using three external targets. Two dihedrals at 0° (noted D^0) and 45° (noted D) and a trihedral (noted T) are necessary to correct for channel imbalance, cross-talk, FR and system gain. Note that in FP, only one trihedral is needed to calibrate the system because of enforcing the reciprocity principle (HV=VH). Even if in CP fewer calibration unknowns need to be estimated, more external targets are required to calibrate the system.

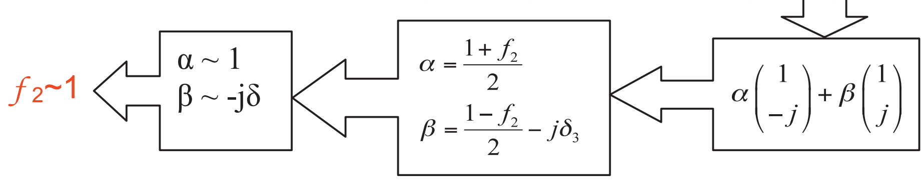
$$\delta_1 = \frac{j}{2}\left(\frac{M^{*D^0}_{RV}}{M^{D^0}_{RH}}\frac{M^{D}_{RV}}{M^{D}_{RH}} - \frac{M^{D}_{RH}}{M^{D}_{RV}}\frac{M^{D^0}_{RV}}{M^{D^0}_{RH}}\right)$$

$$f_1 = \frac{2j}{\dfrac{M^{T}_{RH}}{M^{T}_{RV}} - \dfrac{M^{D}_{RH}}{M^{D}_{RV}}}$$

$$\delta_2 = \left|f_1\right|^2 \frac{M^{D^*}_{RH}}{M^{D^*}_{RV}} - \delta_1^* f_1 - j f_1$$

$$\delta_2 = \left|f_1\right|^2 \frac{M^{D^*}_{RH}}{M^{D^*}_{RV}} - \delta_1^* f_1 - j f_1$$

$$\begin{pmatrix} M_{RH} \\ M_{RV} \end{pmatrix} = A(r,\theta)e^{j\varphi}\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & \delta_2 \\ \delta_1 & f_1 \end{pmatrix}\begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix}\begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix}\begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix}\boxed{\begin{pmatrix} 1 & \delta_3 \\ \delta_3 & f_2 \end{pmatrix}\begin{pmatrix} 1 \\ -j \end{pmatrix}}$$



6. CONCLUSION

In this paper the abilities of a CP system as an alternative mode to the standard dual-pol mode is explored. The biomass quantification directly with CP or FP reconstructed data is shown possible since the estimates over RAMSES P-band data acquired over the Nezer forest show an RMS error of only 6.2 tons/ha for HV' and 6.6 tons/ha for RR whereas for HV the RMS error is 5.8 tons/ha, given that the total biomass is ranging between 25 and 120 tons/ha. Secondly, a technique for retrieving the volume height from a compact polarimetric SAR interferometry system using the Flynn algorithm is described. Then, the equivalence between CP data simulated from FP processed data and FP raw data is established with an interferometric coherence between both higher than 0.9. Finally, a method allowing the calibration of a compact-pol system including the Faraday rotation effect using corner reflectors, a trihedral and two dihedral oriented at 0° and 45°, and assuming a perfect transmission is presented.

7. ACKNOWLEDGMENT

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